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Dose-to-medium vs. dose-to-water: Dosimetric evaluation of dose reporting modes in Acuros XB for prostate, lung and breast cancer

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Original Article

Abstract

Purpose: Acuros XB (AXB) dose calculation algorithm is available for external beam photon dose calculations in Eclipse treatment planning system (TPS). The AXB can report the absorbed dose in two modes: dose-to-water (D_w) and dose-to-medium (D_m). The main purpose of this study was to compare the dosimetric results of the AXB_D_m with that of AXB_D_w on real patient treatment plans. **Methods:** Four groups of patients (prostate cancer, stereotactic body radiation therapy (SBRT) lung cancer, left breast cancer, and right breast cancer) were selected for this study, and each group consisted of 5 cases. The treatment plans of all cases were generated in the Eclipse TPS. For each case, treatment plans were computed using AXB_D_w and AXB_D_m for identical beam arrangements. Dosimetric evaluation was done by comparing various dosimetric parameters in the AXB_D_w plans with that of AXB_D_m plans for the corresponding patient case. **Results:** For the prostate cancer, the mean planning target volume (PTV) dose in the AXB_D_w plans was higher by up to 1.0%, but the mean PTV dose was within ±0.3% for the SBRT lung cancer. The analysis of organs at risk (OAR) results in the prostate cancer showed that AXB_D_w plans consistently produced higher values for the bladder and femoral heads but not for the rectum. In the case of SBRT lung cancer, a clear trend was seen for the heart mean dose and spinal cord maximum dose, with AXB_D_w plans producing higher values than the AXB_D_m plans. However, the difference in the lung doses between the AXB_D_m and AXB_D_w plans did not always produce a clear trend, with difference ranged from -1.4% to 2.9%. For both the left and right breast cancer, the AXB_D_m plans produced higher maximum dose to the PTV for all cases. The evaluation of the maximum dose to the skin showed higher values in the AXB_D_m plans for all 5 left breast cancer cases, whereas only 2 cases had higher maximum dose to the skin in the AXB_D_m plans for the right breast cancer. **Conclusion:** The preliminary dosimetric results from our clinical study showed that the selection of either D_m or D_w in AXB is less likely to produce significant dosimetric differences in the clinical environment. However, the difference between the AXB_D_m and AXB_D_w calculations depends on the disease site, and even for the same type of disease (e.g., lung cancer), the results are patient specific.

Keywords: Acuros XB; Dose-to-Medium; Dose-to-Water; Dose Calculation; Heterogeneity Correction

Introduction

In conventional radiation therapy treatment planning systems (TPS), photon dose calculation algorithms typically report the absorbed dose as dose-to-water (D_w). Dose calculation algorithms employed in the TPS aim to best match the computed results with the measurements, which are performed in water phantoms. In recent years, there has been significant interest in using dose calculation algorithms that are based on Monte Carlo (MC) approach, which can report the absorbed dose in dose-to-medium (D_m) mode. In the D_m mode, the absorbed dose is computed to the medium contained in the dose voxel of the material. Siebers *et al.*[1] suggested that the conversion of D_m to D_w may be desirable in some of the situations when MC-based calculations are used in external beam photon radiation therapy. Currently, dosimetric calibration protocols of external beam photon radiation therapy[2, 3] are based on the D_w mode, and the use of either D_m or D_w (after the conversion of D_m to D_w) for MC-based photon dose calculations remains a debating topic.[4]

Varian's Eclipse TPS (Varian Medical Systems, Palo Alto, CA) has implemented Acuros XB (AXB) dose calculation algorithm, which can report the absorbed dose in both the D_m and D_w options. The AXB utilizes the Linear Boltzmann Transport Equation (LBTE) and solves numerically that describes the macroscopic behavior of ionizing particles as they travel through and interact with matter.[5] For the AXB_D_m, the macroscopic energy deposition cross-section and atomic

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density are based on the material properties of local voxel, whereas for the AXB_D_w, the energy deposition cross-sections are used for the local media.[5–7] Detail descriptions on AXB can be found in the published literature.[5–7]

Several investigators[5–31] have studied the dosimetric impact of AXB using D_m reporting mode, and compared the AXB_D_m results with MC simulations, measurements, and Anisotropic Analytical Algorithm (AAA) calculations. Few studies have reported the difference between the D_m and D_w in AXB using MC simulations[23], measurements[24, 25, 26], and computed tomography (CT) data of real patients for nasopharygeal carcinoma[26] (planning technique used: intensity modulated radiation therapy (IMRT)), and soft-tissue sarcoma[27] (planning technique used: volumetric modulated arc therapy (VMAT)). Literature review shows that studies comparing AXB_D_m and AXB_D_w calculations on real clinical cases are limited. Hence, it is essential to further investigate if the selection of either D_m or D_w in AXB will make a significant dosimetric impact in the clinical environment. The major purpose of this study was to compare the dosimetric results of the AXB_D_m calculations with that of AXB_D_w calculations on real patient treatment plans for the prostate, lung, and breast cancer.

Methods and Materials

Patient selection and CT simulation

In this retrospective study, all dosimetric data were obtained from 21st Century Oncology, Naples, Florida, USA. The patient selection was done based on the localizations of the tumor, which included prostate cancer (Group 1), stereotactic body radiation therapy (SBRT) lung cancer (Group 2), right breast cancer (Group 3), and left breast cancer (Group 4). Each group consisted five cases previously treated with external beam photon radiation therapy at 21st Century Oncology, Naples, Florida, USA. All patients underwent standard CT simulation on a Phillips Brilliance CT Scanner. The CT scans were acquired using 512 × 512 pixels and 2.5 mm slice thickness. After the CT simulation, DICOM CT images were transferred to the Eclipse TPS for contouring and planning purpose.

Contouring

All four groups of patients included the planning target volume (PTV), which was expanded from the clinical target volume (CTV) drawn by the physician. Additionally, organs at risk (OARs) were delineated based on the axial CT images. The OARs of each group of patients are provided in **Table 1**.

Treatment planning

Treatment plans of all four groups of patients were generated in the Eclipse TPS (version 11.2) using RapidArc, IMRT, and 3D conformal radiation therapy (3DCRT) (Energy: 6 MV X-ray; Machine: TrueBeam (Varian Medical Systems, Palo Alto, CA, USA)). For prostate cases, the total dose prescribed to the PTV was 81 Gy with a daily dose of 1.8 Gy in 45 fractions. The prostate cancer treatment plans were generated using a single-full-arc. For the SBRT lung cases, the total dose prescribed to the PTV was 50 – 60 Gy with a daily dose of 10 or 12 Gy in 5 fractions. The SBRT lung cancer treatment plans were generated using 5-field IMRT (n = 4) and 2-partial-arc RapidArc (n = 1) techniques.

For the right breast cancer cases, the total dose prescribed to the PTV was 45 Gy (n = 4) and 46.8 Gy (n = 1) with a daily dose of 1.8 Gy. The treatment plans were generated using 2-tangent fields IMRT (n = 4) and 2-tangent fields 3DCRT (n = 1) techniques. For all 5 left breast cancer cases, the total dose prescribed to the PTV was 45 Gy with a daily dose of 1.8 Gy in 25 fractions. The treatment plans were generated using 2-tangent fields IMRT (n = 3) and 2-partial-arc RapidArc (n = 2) techniques. The isocenter in all treatment plans was placed at the center of the PTV.

The treatment plans of all four groups of patients were optimized using the Varian Eclipse Progressive Resolution Optimizer (version 11.2) with an objective of meeting the planning objectives of institutional guidelines. After the optimization process, each treatment plan was calculated using AXB_D_m (version 11.2) and AXB_D_w (version 11.2). The dose calculation grid size was set to 2 mm for all the cases. The calculated treatment plans were normalized such that the prescribed dose covered at least 95% of the PTV.

TABLE 1: Organs at risk (OARs) for four different groups of patients.

	Prostate Cancer (Group 1)	SBRT Lung Cancer (Group 2)	Left Breast Cancer (Group 3)	Right Breast Cancer (Group 4)
OARs	Rectum	Ipsi-Lung	Contra-Breast	Contra-Breast
	Bladder	Contra-Lung	Ipsi-Lung	Ipsi-Lung
	Femoral Heads	Heart	Contra-Lung	Contra-Lung
		Spinal Cord	Heart	Heart
			Skin	Skin

Abbreviations: Ipsi = Ipsi-lateral; Contra = Contra-lateral; SBRT = Stereotactic Body Radiation Therapy

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Plan evaluation

The dose-volume histograms (DVHs) of both the AXB_D_m and AXB_D_w were generated in the Eclipse TPS. Treatment plans were evaluated for various dosimetric parameters. For a comparative purpose, the relative difference (Δ) in the corresponding dosimetric parameter (for example, mean dose, maximum dose, etc.) between the AXB_D_m and AXB_D_w plans of the same case was calculated using **Equation 1**.

$$\Delta(x) = \frac{AXB\_D_w(x) - AXB\_D_m(x)}{AXB\_D_w(x)} \times 100 \text{ ---------(1)}$$

where, x is the corresponding dosimetric parameter in the AXB_D_w and AXB_D_m plans of the same case.

Results

The dosimetric results in the AXB_D_m and AXB_D_w plans of all four groups of patients are presented in **Figures 1-4**.

Prostate cancer

For the prostate cancer, in comparison to the AXB_D_m plans, the AXB_D_w plans produced a higher mean dose to the PTV (Δ_{avg}=0.8%), rectum (Δ_{avg}=0.4%), bladder (Δ_{avg}=1.4%), and femoral heads (Δ_{avg}=2.5%). The relative rectal volume exposed to radiation was higher in the AXB_D_w plans with the average relative differences of 0.6% for V_{30}, 0.9% for V_{50}, and 1.3% for V_{70}. Similarly, the relative bladder volume exposed to radiation was higher in the AXB_D_w plans with the average relative differences of 1.4% for V_{30}, 2.3% for V_{50}, and 4.5% for V_{70}.

SBRT lung cancer

For SBRT lung cancer, the mean dose in the AXB_D_w plans was consistently higher for the heart (Δ_{avg}=1.3%) and esophagus (Δ_{avg}=0.7%) but almost identical for the PTV (Δ_{avg}=-0.1%). In evaluating the mean dose to the ipsi-lung and contra-lung, no clear trend was observed, with AXB_D_w plans producing higher values in 2 cases for the ipsi-lung and in 3 cases for the contra-lung. For the ipsi-lung, the V_5, V_{10}, and V_{20} were similar in the AXB_D_w and AXB_D_m, with an average relative difference within ±0.4%. For the V_5 of the contra-lung, the averaged difference is -0.2% (range, -1.3% to 0.1%) with higher values in the AXB_D_w plans in 3 cases. The maximum dose to the spinal cord was consistently higher (Δ_{avg}=2.1%) in the AXB_D_w plans, with a relative difference ranged from 1.4% to 4.4%.

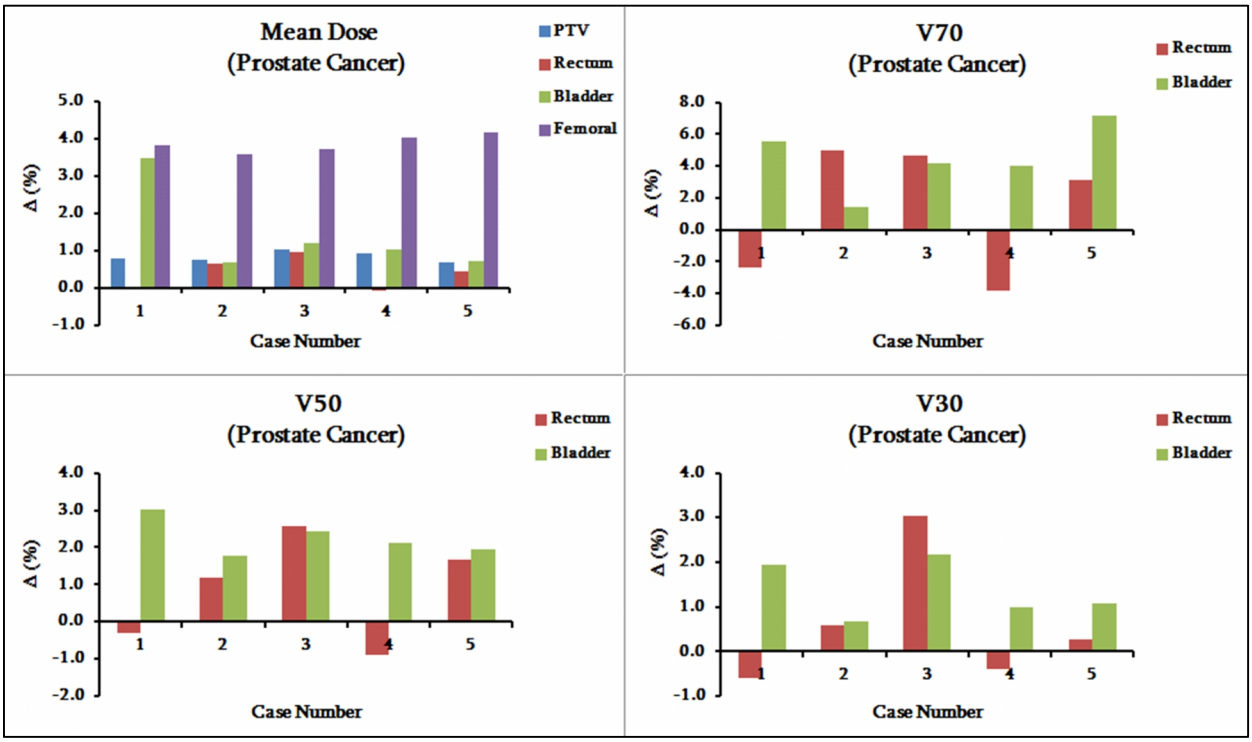

FIG. 1: Relative difference (Δ) in dosimetric results between the AXB_D_w and AXB_D_m plans for 5 different prostate cancer cases. V_n means percentage volume irradiated by n Gy or more of a certain structure. The Δ is defined in **Equation 1**.

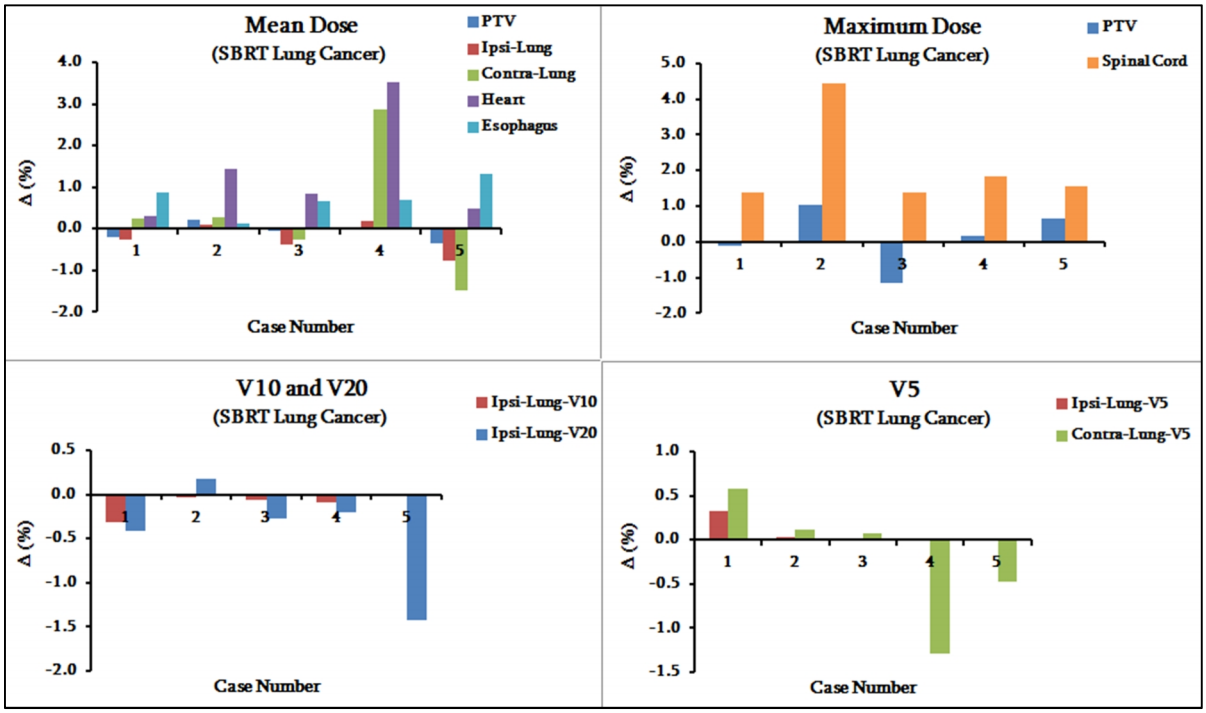

FIG. 2: Relative difference (Δ) in dosimetric results between the AXB_D_w and AXB_D_m plans for 5 different SBRT lung cases. V_n means percentage volume irradiated by n Gy or more of a certain structure. The Δ is defined in **Equation 1**.

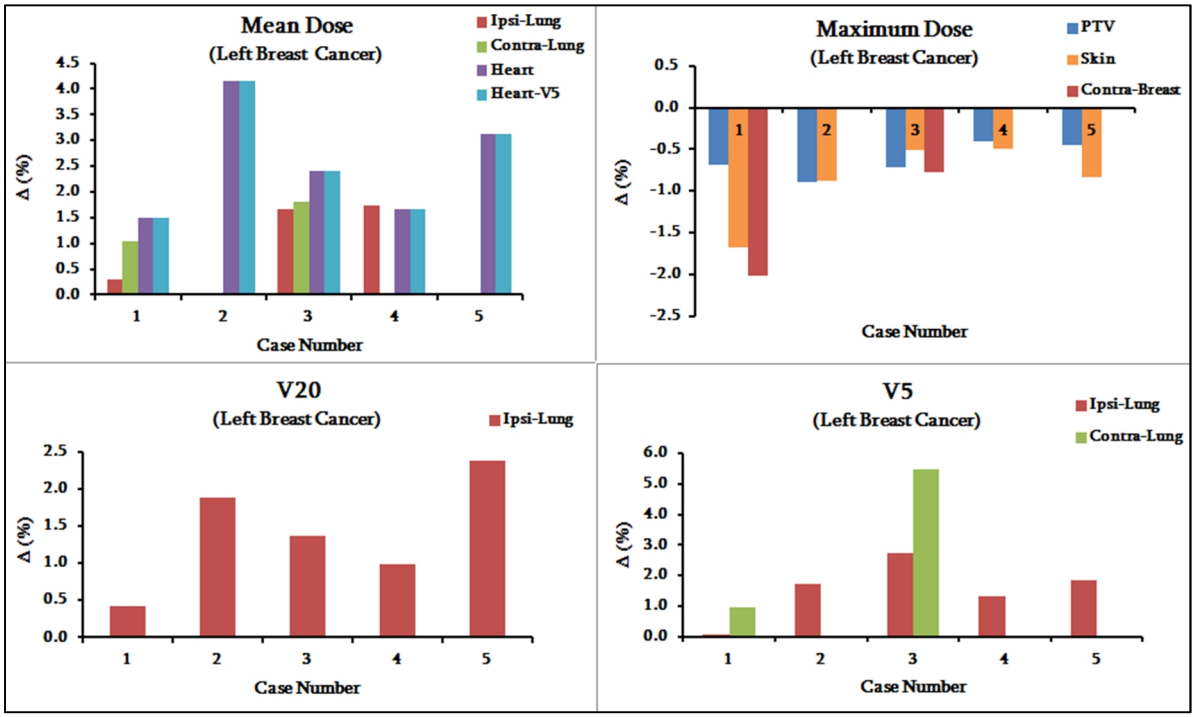

FIG. 3: Relative difference (Δ) in dosimetric results between the AXB_D_w and AXB_D_m plans for 5 different left breast cancer cases. V_n means percentage volume irradiated by n Gy or more of a certain structure. The Δ is defined in **Equation 1**.

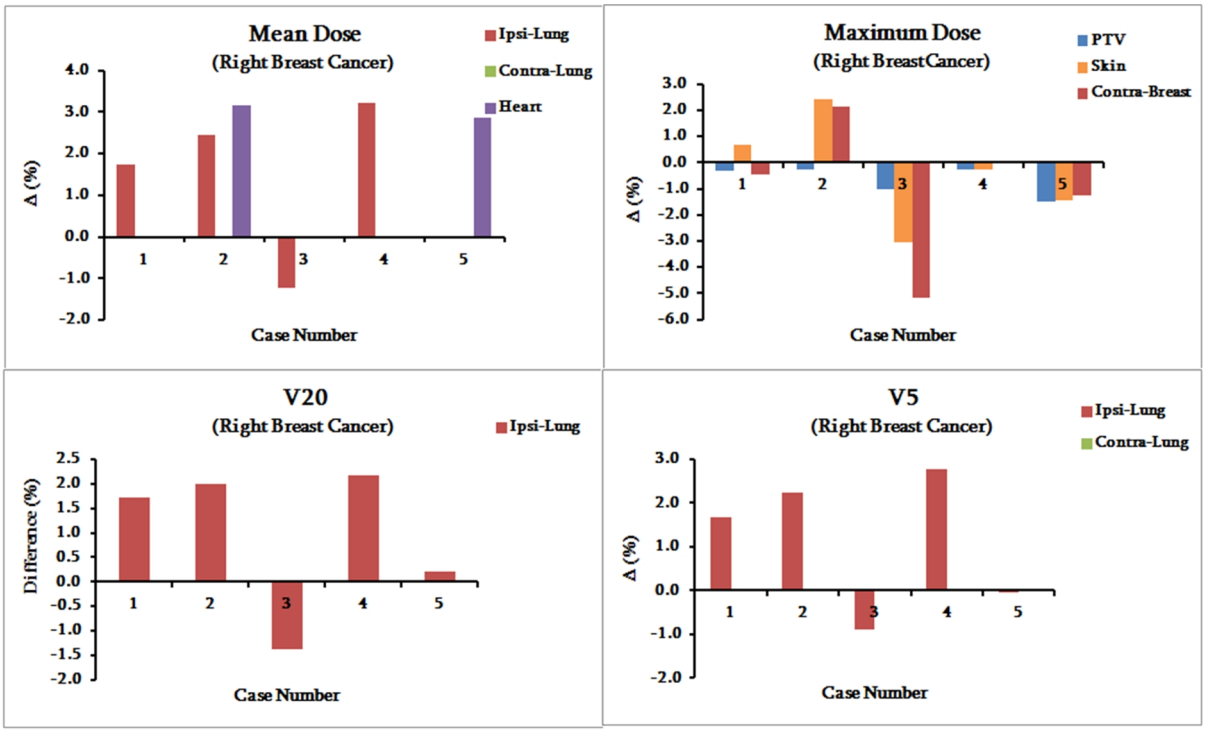

FIG. 4: Relative difference (Δ) in dosimetric results between the AXB_D$_w$ and AXB_D$_m$ plans for 5 different right breast cancer cases. V$_n$ means percentage volume irradiated by n Gy or more of a certain structure. The Δ is defined in **Equation 1**.

Left breast cancer

For the left breast cancer, the difference in the PTV maximum dose between the AXB_D$_w$ and AXB_D$_m$ plans ranged from -0.4% to -0.9%. On average, the mean dose in the AXB_D$_w$ plans was higher for the ipsi-lung (Δ_{avg}=0.7%), contra-lung (Δ_{avg}=0.6%), and heart (Δ_{avg}=2.6%), whereas AXB_D$_m$ plans had higher values for the maximum dose to the skin (Δ_{avg}=-0.9%) and contra-breast (Δ_{avg}=-0.6%). For the ipsi-lung, the AXB_D$_w$ plans had higher values in the case of V$_5$ (Δ_{avg}=1.5%) and V$_{20}$ (Δ_{avg}=1.2%).

Right breast cancer

For the right breast cancer, the difference in the PTV maximum dose between the AXB_D$_w$ and AXB_D$_m$ plans ranged from -0.3% to -1.5%. The mean dose in the AXB_D$_w$ plans was higher for the ipsi-lung (Δ_{avg}=1.2%) and almost identical for the majority of the cases for the contra-lung and heart (except for case #2 and #5). On average, the AXB_D$_m$ plans had higher values for the maximum dose to the skin (Δ_{avg}=-0.3%) and contra-breast (Δ_{avg}=-0.9%). In the case of ipsi-lung, on average, the AXB_D$_w$ plans had higher values for the V$_5$ (Δ_{avg}=1.2%) and V$_{20}$ (Δ_{avg}=0.8%) when compared to the AXB_D$_m$ plans.

Discussion

The dosimetric impact of D$_m$ and D$_w$ reporting mode in AXB was investigated for the prostate, SBRT lung, and breast cancer. The AXB_D$_m$ and AXB_D$_w$ plans were evaluated based on the results derived from the DVH in the Eclipse TPS. The preliminary results from the clinical cases in this study showed that the differences in dosimetric results between the AXB_D$_m$ and AXB_D$_w$ plans depend on the tumor type. For instance, the mean PTV dose in the AXB_D$_w$ plans was slightly higher (relative difference up to 1.0%) for the prostate cancer when compared to the mean PTV dose in the AXB_D$_w$ plans for the SBRT lung cancer (relative difference within ±0.3%). Kan *et al.*[26] and Fogliata *et al.*[27] also reported higher values calculated by AXB_D$_w$ when compared to the ones calculated by AXB_D$_m$.

The analysis of the OAR results for the prostate cancer (**Figure 1**) showed that the AXB_D$_w$ plans consistently produced higher values for the bladder and femoral heads but not for the rectum. In the case of SBRT lung (**Figure 2**), a clear trend was seen for the heart mean dose and spinal cord maximum dose, with AXB_D$_w$ plans producing higher values when compared to the AXB_D$_m$ plans. However, the difference in the lung doses between the AXB_D$_m$ and AXB_D$_w$ plans did not always produce a clear trend, with the relative difference ranged from -1.4% to 2.9%. For both the left and right breast cancer, we observed higher maximum dose to the PTV as

well as higher mean dose to the heart in the AXB_D_m plans, and this was true for all cases. The evaluation of the maximum dose to the skin showed higher values in the AXB_D_m plans for all 5 left breast cancer cases, whereas only 2 cases had higher maximum dose to the skin in the AXB_D_m plans for the right breast cancer cases.

The results presented in this study demonstrated that the difference between the AXB_D_m and AXB_D_w calculations is dependent on the tumor type, and even for the same type of tumor, the results are patient specific. The use of D_m vs. D_w for external beam photon radiation therapy is an interesting debating topic for the medical physics community.[4] On one hand, the supporters of D_m reason that (i) conversion from D_m to D_w adds uncertainty in dose calculations due to uncertainties in computed stopping power ratios; (ii) changing to D_m will have minimal impact on the treatment protocols; (iii) D_m is more likely to provide a better measure of biological response; and (iv) conversion of the D_m to D_w defeats a potential advantage of using MC-based dose calculation algorithms. On the other hand, the supporters of D_w argue that (i) commissioning beam data are always measured in water; (ii) clinical experience in terms of tumor/tissue response is based on D_w; (iii) dosimetry calibration protocols are based in water; and (iv) conversion from CT numbers to media results uncertainty in the medium type and composition.

Conclusion

The preliminary dosimetric results from our clinical study showed that the selection of either D_m or D_w in AXB is less likely to produce significant dosimetric differences in the clinical environment. However, the difference between the AXB_D_m and AXB_D_w calculations depends on the disease site, and even for the same type of disease (e.g., lung cancer), the results are patient specific. Future studies need to include large cohort of clinical cases with different types of cancer. Also, it is recommended to investigate the dosimetric impact of the treatment technique (e.g., 3DCRT, IMRT, and VMAT) on the AXB_D_m and AXB_D_w calculations for different types of cancer.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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